OPTIMAL LOCATION OF LOGISTICS TERMINALS CONSIDERING ENVIRONMENTAL IMPACTS

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Abstract

This paper presents a mathematical model for determining the optimal size and location of logistics terminals using genetic algorithms. The model explicitly incorporates the traffic conditions on road network and the environmental impacts by freight transport. The model was successfully applied to a road network in the Kyoto-Osaka area for comparing two cases of minimising the total costs and CO_2 emissions.

INTRODUCTION

Urban freight transport has faced various problems such as congestion, environment, energy saving and labor problems. Especially in large cities the environmental problems including air pollution, noise and vibration issues generated great social concern and the traffic congestion on trunk roads has become worse year by year. The urban goods are mainly carried by trucks and the harmful gas emission from diesel trucks is one of major sources of air pollution in urban areas. Just-In-Time transport systems have become popular in industry and a small loads of goods are frequently carried to meet the high levels of needs for customers. It leads to decrease the load factor of urban pickup/delivery trucks and accelerate the traffic congestion on urban roads. Moreover global environmental issues get more attention and the CO_2 (carbon dioxide) emissions need to be reduced relating to road traffic for preventing the global warming effects.

In such circumstance it is needed to establish efficient freight transport systems for solving these problems. As one of solutions, it is proposed to build public logistics terminals surrounding large cities in Japan. Logistics terminals are complex facilities with multiple functions that are designed to meet various needs in supply chain management systems using advanced information systems and also contribute to establish efficient freight transport through mechanization and automation of material handling. Similar ideas are proposed in Germany (Ruske, 1994) and the Netherlands (Janssen and Oldenburger, 1991). Logistics terminals will be built together with interchanges of expressways. These terminals can also facilitate the implementation of cooperative freight transport system. As Taniguchi, *et al.* (1995) concluded, truck traffic can be reduced by adopting cooperative freight transport system in urban areas. Therefore it is likely that the introduction of logistics terminals with cooperative freight transport systems will alleviate many problems concerning freight transport. The concept of logistics terminals are also applicable to underground new freight transport systems proposed by Koshi, *et al.*(1992) which use electric vehicles automatically operated in exclusive lanes .

Planning the size and location of facilities are traditional problems (Weber, 1929; Beckman, 1968; Drezner, 1995; Daskin, 1995) and have been studied by applying the methodology of operations research. Optimisation problems relating to the location of transport terminals have been modelled together with the routing of goods (Hall, 1987; Daganzo, 1996). Campbell (1990) developed a continuous approximation model for relocating terminals to serve expanding demand. Noritake and Kimura (1990) developed models to identify the optimal size and location of seaports using separable programming techniques.

This paper focuses on optimising the size and location of logistics terminals, taking into account road environmental issues, especially the air pollution. A mathematical model was developed for optimising the size and location of logistics terminals using queuing theory and non-linear programming. The model explicitly takes into account the traffic conditions on road network to determine the size and location of logistics terminals. It is useful to use genetic algorithms to quickly obtain approximate optimal solution of large scale non-linear programming problems. The objective functions of this model are: (a) the total costs that are incurred at logistics terminals and during transport; (b) CO_2 (carbon dioxide) emissions.

MODEL

The model described here aims to identify the optimal size and location of logistics terminals. Figure 1 shows the structure of the logistics system that is investigated within this paper. It is assumed that the movement of goods is divided into two parts: Line-haul --- which is usually long distance transport by large trucks on expressways, and Local pick-up/delivery --- which is usually transport over short distance by small trucks on urban roads. Logistics terminals are the connection points between the line-haul and pick-up/delivery of goods where transshipments are usually performed. Sometimes goods may be stored at terminals, but no inventory is considered in this study. Points where freight is generated and attracted are set for line-haul and pick-up/delivery trucks within the road network. These points are refereed to as centroids.

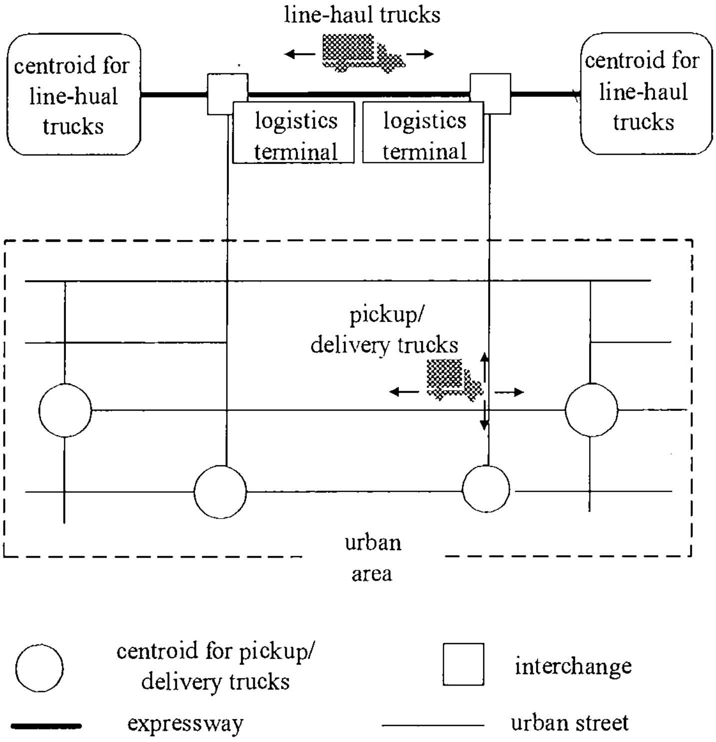


Figure1 Structure of logistics system investigated

The mathematical model developed here has following four features: (1)The model determines optimal location of logistics terminals from candidate nodes that are discretely specified within the road network; (2) The model takes into account the trade-offs between transport costs and facility costs (such as construction, maintenance, land and truck operation costs in the terminals); (3)A planner can determine the optimal size and location of logistics terminals but cannot control the distribution and assignment of truck traffic; (4) The distribution of the movement of goods is determined for each pair of centroids for line-haul trucks and pickup/delivery trucks. Some distribution patterns of goods described in (4) go through a logistics terminal and others go through other logistics terminals. In other words each truck can choose any logistics terminals to minimise its costs.

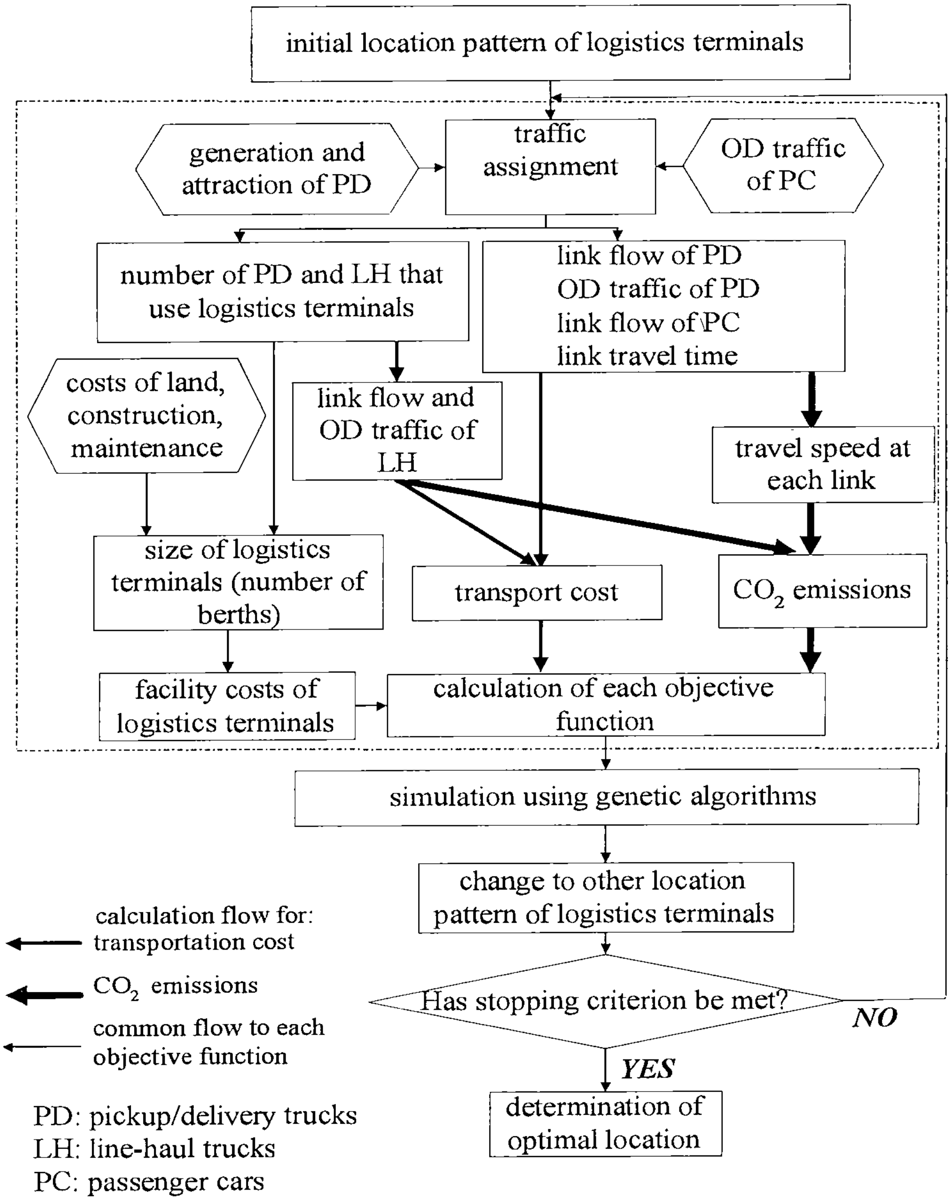


Figure 2 Structure of the model for identifying optimal size and location of logistics terminals

Figure 2 shows the structure of the model for identifying the size and location of logistics terminals, which has two levels of optimisation problems. The upper level problem describes the behaviour of planner for minimising the total costs, which consist of both transport costs and facility costs, or CO_2 emissions. The model simultaneously determines the optimal size and location of logistics terminals. The lower level problem describes the behaviour of each company and each truck in choosing optimal logistics terminals and transport routes. The assignment of pick-up/delivery truck traffic is performed together with passenger car traffic. The mathematical formulation of the model is given below (Taniguchi, *et al.*, 1997).

(upper level problem)

$$\underset{\mathbf{x}\in \mathrm{X},\mathbf{y}\in \mathrm{Y}}{\text{minimise}}\ f_1(\mathbf{x},\mathbf{y},\mathbf{z}^*) \tag{1}$$

subject to

$$\mathbf{g}_1(\mathbf{x},\mathbf{y},\mathbf{z}^*) \le 0 \tag{2}$$

(lower level problem)

$$\underset{\mathbf{z}\in \mathbf{Z}}{\text{minimise}}\ f_2(\mathbf{x},\ \mathbf{z}\ ) \tag{3}$$

subject to

$$\mathbf{g}_2(\mathbf{x},\ \mathbf{z}) \le 0 \tag{4}$$

where,

$\mathbf{x}$: vector that represents location pattern of candidate nodes for logistics terminals

($\mathbf{x} = (x_1,\ x_2,\ldots,\ x_i,\ldots,\ x_n)$, $x_i := 1$, if logistics terminal is located at candidate node i ;
$= 0$, if not)

$\mathbf{y}$: vector that represents the number of berths in candidate nodes for logistics terminals

$\mathbf{z}$: vector that represents behaviour of trucks

$\mathbf{z}^*$:vector that represents behaviour of trucks under $\mathbf{x}$ (solution of lower level problem)

X: sets of vector $\mathbf{x}$

Y: sets of vector $\mathbf{y}$

$\mathbf{Z}$:sets of vector $\mathbf{z}$

f_1 , f_2 : objective function of a planner and a truck, respectively

$\mathbf{g}_1$, $\mathbf{g}_2$: constraint vector to a planner and a truck, respectively.

These equations represent non-linear programming with two levels. This model adopted two objective functions for f_1 : (1) The total costs --- which are composed of transport costs and facility costs, including construction, maintenance, land and truck operation costs within the terminal; (2) CO_2 emissions. The facility costs are related to the size of logistics terminals which is represented by the number of berths. The facility costs can be estimated based on queuing theory (Taniguchi, *et al.*, 1996). The lower level problem presents a combined distribution-assignment model (Beckman, *et al.*, 1956; Evans, 1976) which incorporates the equal travel time principle for assignment and variable demand for distribution between a centroid for pick-up/delivery truck and a logistics terminal.

The lower level problem simultaneously deals with passenger car traffic and pick-up/delivery truck traffic and both traffic modes satisfy the user equilibrium condition of the network. A unique solution for this lower level problem is assured since the set of feasible solutions for the problem is convex and the objective function is strictly convex (Sheffi,1985).

The upper level problem is a non-linear optimisation problem with discrete variables representing the location pattern of logistics terminals. To solve this type of problem exactly requires a very long computation time and if there are many candidate logistics terminals, it is impossible in practice. For example if the number of candidate nodes for logistics terminals is 20, then the required calculation time is equal to $2^{20}-1=1,048,575$ and calculation becomes practically impossible. Therefore some approximate method is required and genetic algorithms have been applied here. Genetic algorithms provide an effective method to quickly obtain approximate optimal solution (Goldberg, 1989).

CASE STUDIES

The model described above was applied to an actual road network in the Kyoto-Osaka area, Japan as shown in Figure 3, to determine the optimal size and location of logistics terminals. This network is planned for the year 2010, and 16 candidates for logistics terminals are specified along with several planned expressways. The network has two centroids for line-haul trucks in East and West Japan and 36 centroids for pick-up/delivery trucks and passenger cars within the Kyoto-Osaka area. For passenger cars 6 nodes outside the area are also included in the network. In Figure 3 ordinary road links represent national highways and main local roads. Predicted O-D traffic volume levels in 2010 existed for passenger and freight traffic, and these were used in all subsequent calculations. But since it is difficult to predict the amount of goods needed in obtaining the number of trucks using logistics terminals, the present amount of goods was used in Case 1, and the amount of 1.5 times was used in Case 2. The land prices at the candidate nodes for logistics terminals are shown in Figure 3.

Figure 4 shows the result for Case 1. Two nodes (1 and 15) were selected as optimal solutions. The terminals 1 and 15 are located at the junction of expressways and near large cities which have large demands for goods movement. The terminal 1 was selected in spite of its high land price as shown in Figure 3. Thus accessibility to large cities and interurban expressways is a significant factors in selecting logistics terminals. In Figure 4 many ordinary roads indicate heavy congestion, especially near Osaka. This leads to an increase of transport costs and that is the reason why terminals close to large cities were chosen as the location for the optimal terminals. Figure 4 also shows the influence area of each selected terminal, and Table 1 indicates the optimal number of berths in each of the selected logistics terminals. Terminal 1 processes a larger amount of goods generated and attracted in Osaka than in Kyoto, and so the required number of berths is greater than that of terminal 15, which is close to Kyoto, though the influence area of terminal 1 is smaller than that of terminal 15.

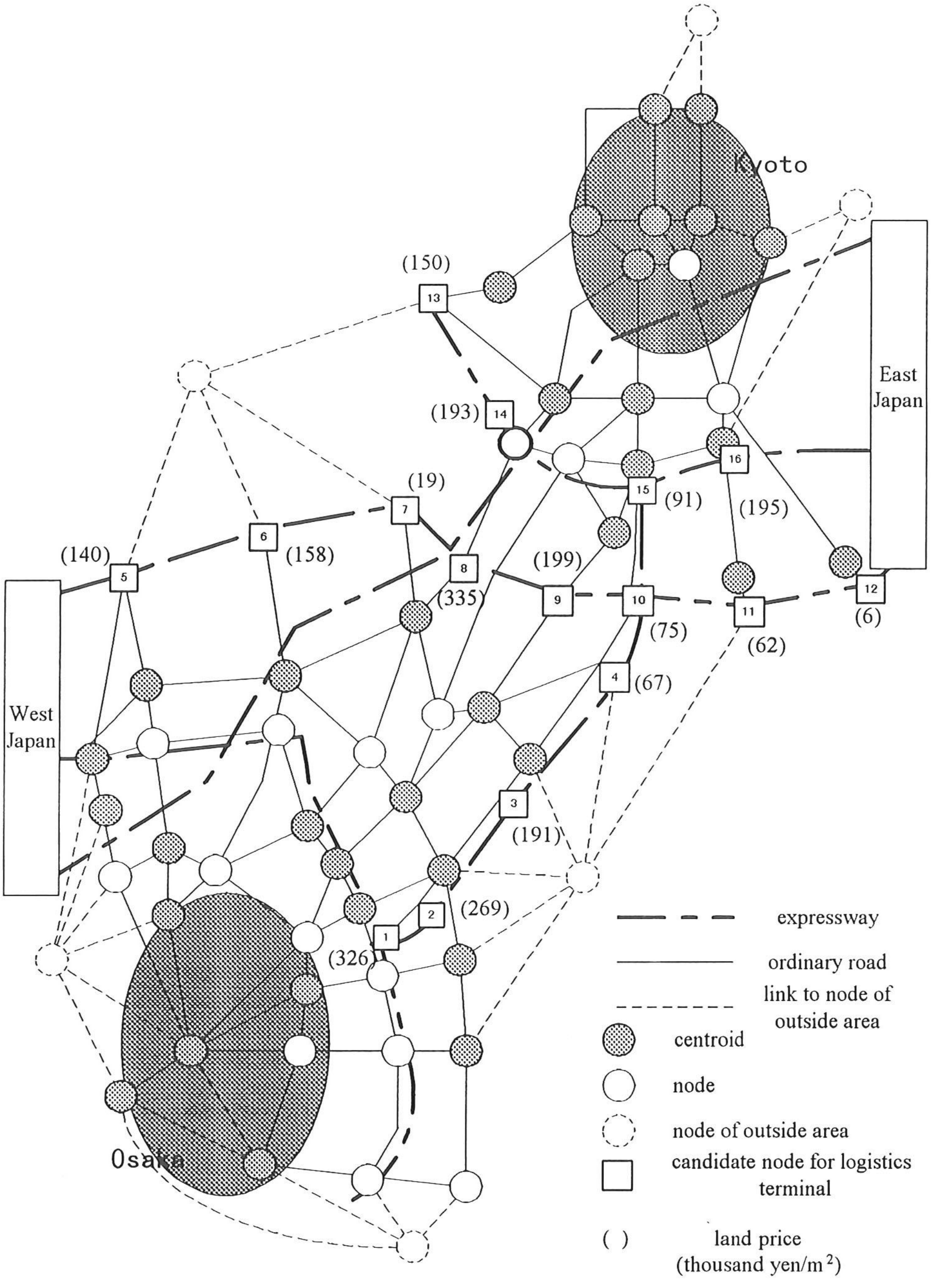
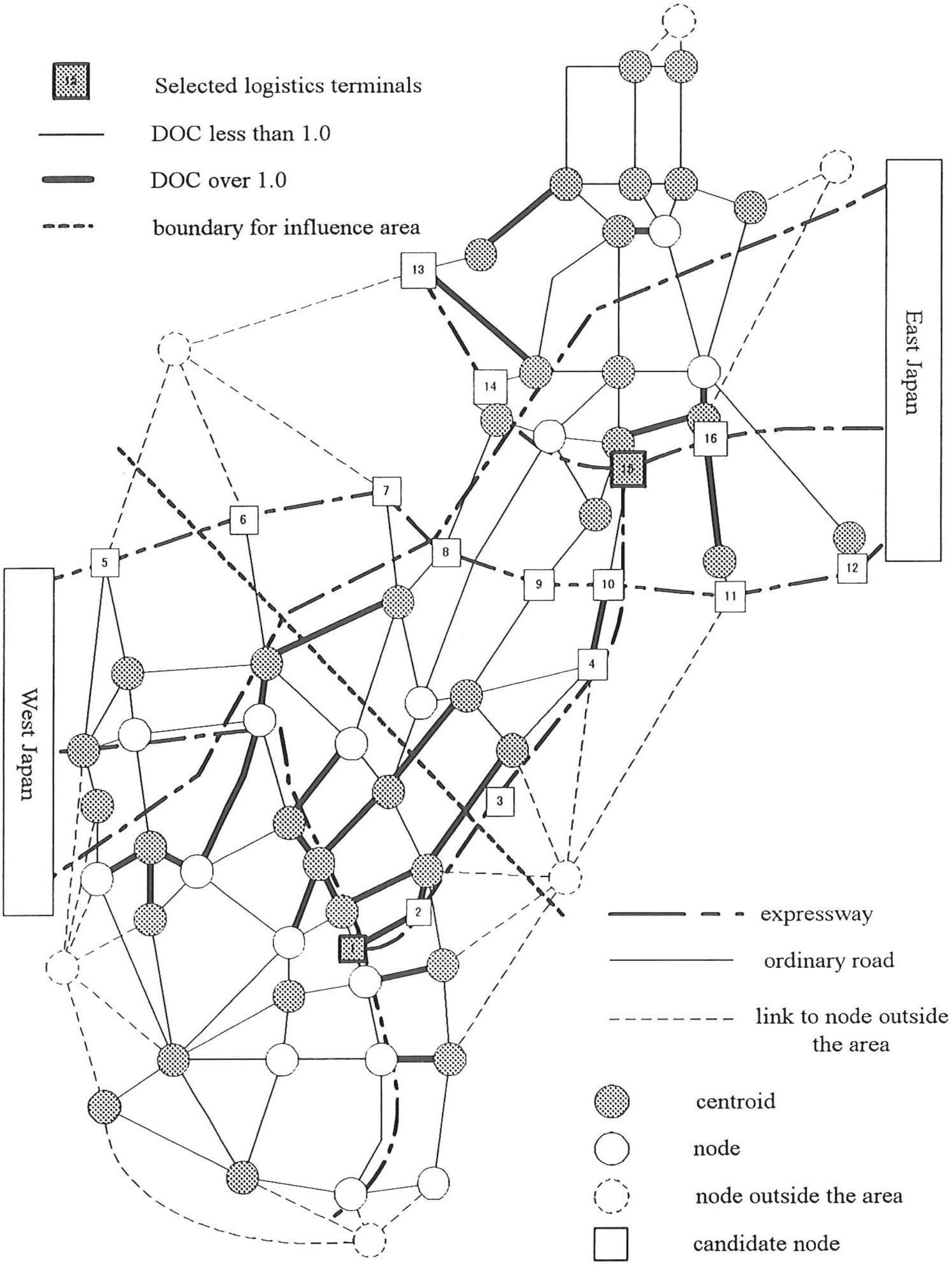


Figure 3 Road network in the Kyoto-Osaka area and candidate nodes for logistics terminals



DOC: Degree of congestion

Figure 4 Selected logistics terminals and degree of congestion on links (Case 1, the objective function: total costs)

Table 1 Optimal number of berths in logistics terminals (Case 1, the objective function: total costs)

ternimal number	line-haul trucks	pickup/delivery trucks	total
1	435	1791	2226
15	209	859	1068

Table 2 Comparison of optimal location of logistics terminals for minimising each objective function

Case	total costs	CO_2 emissions
1	1, 15	1, 15
2	1, 15	1, 2, 15

Table 2 shows the comparison of optimal location of logistics terminals selected to minimize each objective function. Table 2 indicates that the optimal location for Case 1 is same (terminal 1 and 15) for two objective functions of total costs and CO_2 emissions. However, for Case 2 the logistics terminal 2 is added to the optimal solution for minimising the CO_2 emissions, although the same location is selected for minimising the total costs. This change can be explained as follows. In Case 2 the amount of goods was increased by 1.5 times of Case 1 that led to the increase of line-haul and pickup/delivery trucks by 1.5 times, since the same level of load factor was assumed for both cases. This led to more congestion; the degree of congestion on 167 links out of all 218 links were increased and the average of degree of congestion changed to 0.82 for Case 2, whereas it was 0.80 for Case 1. Especially access roads to the terminals 1 and 15 were heavily congested. For example the degree of congestion on the link that approaches the terminal 1 from south was increased by 0.07 (from 0.91 to 0.98) and it was increased by 0.28 (from 1.02 to 1.30) on the other link that approaches the terminal 15 from north. Consequently the travel speed in these access roads was reduced and CO_2 emissions were increased, and then the additional logistics terminal 2 was required for minimising the CO_2 emissions.

Table 3 shows the comparison of costs and CO_2 emissions in various terminal location patterns. For minimising total costs, the pattern (1, 2, 5 and 15) that is the second best solution, indicates only 0.4% increase in costs compared with the optimal solution. If another node (2 or 3) is selected instead of node 1, the total costs increased by 12.5% and 72.5% respectively from the optimal solution. This is due to the higher increase of transport costs than the reduction of facility costs that are mainly generated by low land price. These two cases substantially produced more CO_2 emissions than the optimal case as shown in Table 3, because the transport distance of line-haul trucks was increased and it led to generate more congestion on access roads to Osaka City. It can be noted that locating logistics terminals close to large cities is important for minimising the CO_2 emissions as well as the total costs. Building logistics terminals in all candidate nodes resulted in 13.4% worse in terms of costs and 2.6% worse in terms of CO_2 emissions. The disperse location pattern of logistics terminals increases the transport distance of line-haul trucks and consequently pushes up the total costs and CO_2 emissions.

Table 3 Comparison of costs and CO_2 emissions in various terminal location (Case 1)

terminal location	transport costs (mill. yen/day)	facility costs (mill. yen/day)	total costs (mill. yen/day)	change from optimal (%)
1, 15	303	414	717	optimal
1, 2, 5, 15	310	410	720	0.4
2, 15	400	407	807	12.5
3, 15	845	393	1238	72.5
all nodes	405	409	813	13.4
1, 14	305	419	725	1.0

terminal location	CO_2 emissions (ton/day)	change from optimal (%)
1, 15	4105	optimal
1, 2, 5, 15	4107	0.0
2, 15	4196	2.2
3, 15	4544	10.7
all nodes	4213	2.6
1, 14	4105	0.0

CONCLUSIONS

A mathematical model was developed to determine the optimal size and location of logistics terminals explicitly taking into account the traffic conditions within road network. The model can incorporate the environmental impacts, especially the CO_2 emissions. It identifies the approximate optimal location of logistics terminals using genetic algorithms for minimising the objective function such as the total costs and the CO_2 emissions. This model was successfully applied to an actual road network in the Kyoto-Osaka area and 16 candidate nodes near the interchanges of expressways were assumed. The approximate optimal location was selected at junctions of expressways and close to large cities, because of the heavy congestion on many ordinary roads which generates an increase of transport costs.

In comparison between two cases of minimising the total costs and the CO_2 emissions, the same location was selected for both cases when the generation of amount of goods was small. But if it was increased by 1.5 times, one more terminal was added to the optimal solution for minimising the CO_2 emissions. This is attiributed to effects of road congestion on access roads to the logistics terminal.

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